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(54) **INTEGRATED PHOTOVOLTAIC PANEL CIRCUITRY**

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(58) **Field of Classification Search**

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See application file for complete search history.

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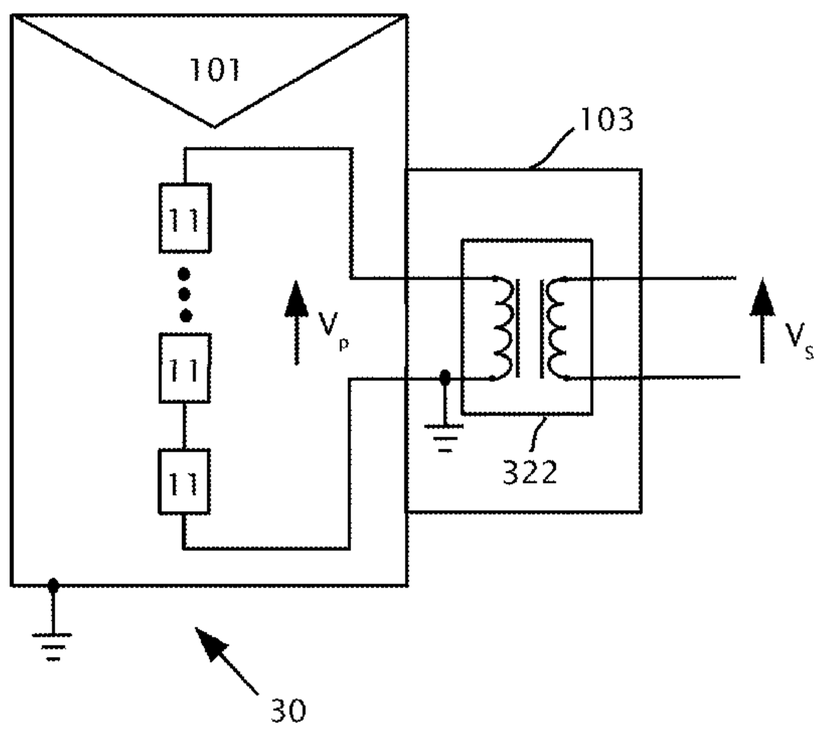
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(57) **ABSTRACT**

A photovoltaic module is presented, which may include a photovoltaic panel and a converter circuit having a primary input connected to the photovoltaic panel and a secondary output galvanically isolated from the primary input. The primary input may be connectible to multiple input terminals within a junction box and at least one of the input terminals may be electrically connected to a ground. The photovoltaic module may include multiple interconnected photovoltaic cells connected electrically to multiple connectors (for example bus-bars). The photovoltaic module may include input terminals operable for connecting to the connectors and an isolated converter circuit. The isolated converter circuit may include a primary input connected to the input terminals and a secondary output galvanically isolated from the primary input.

21 Claims, 8 Drawing Sheets



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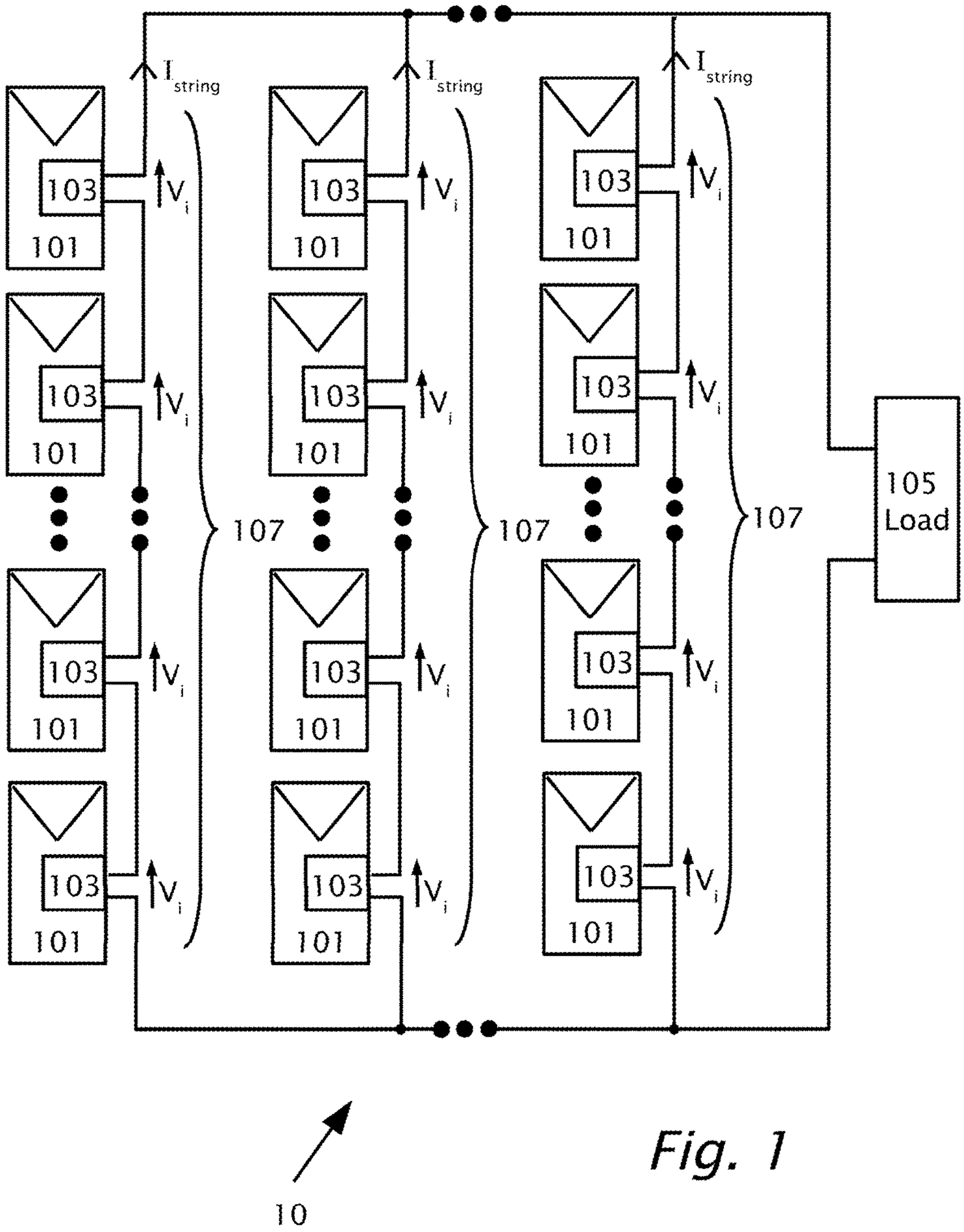


Fig. 1

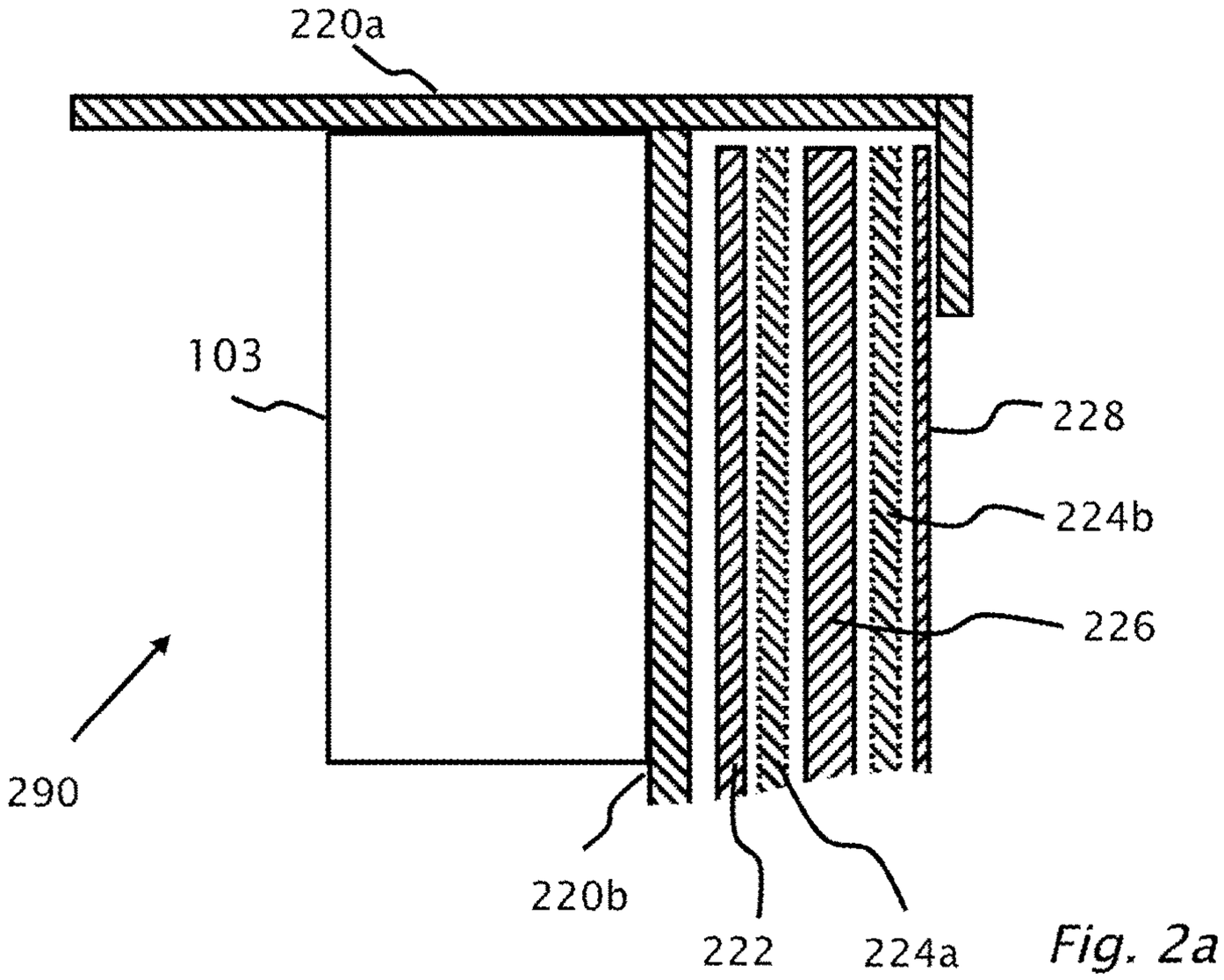

220a
103
228
224b
226
290
220b
222
224a

Fig. 2a

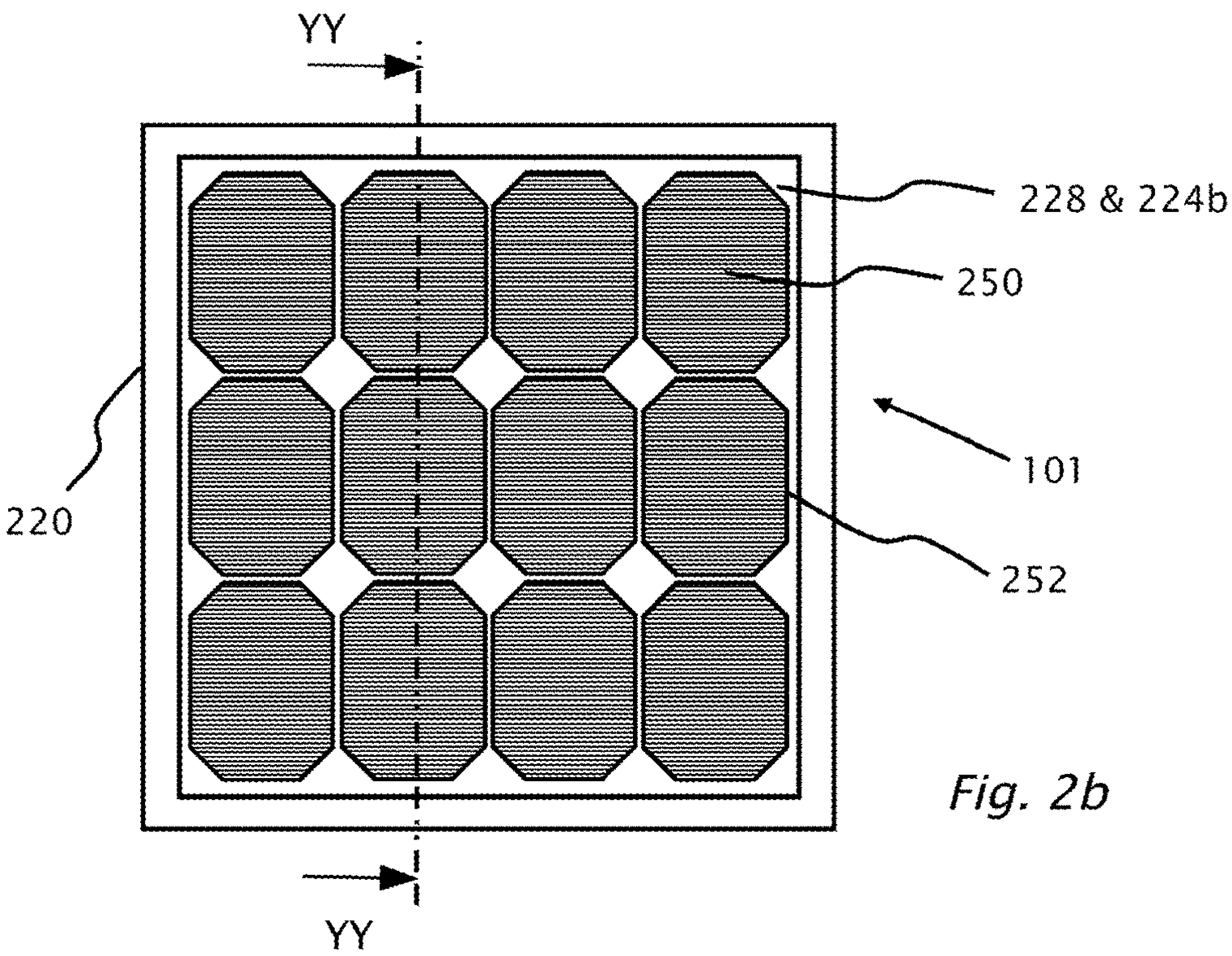

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228 & 224b
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101
220
252
YY

Fig. 2b

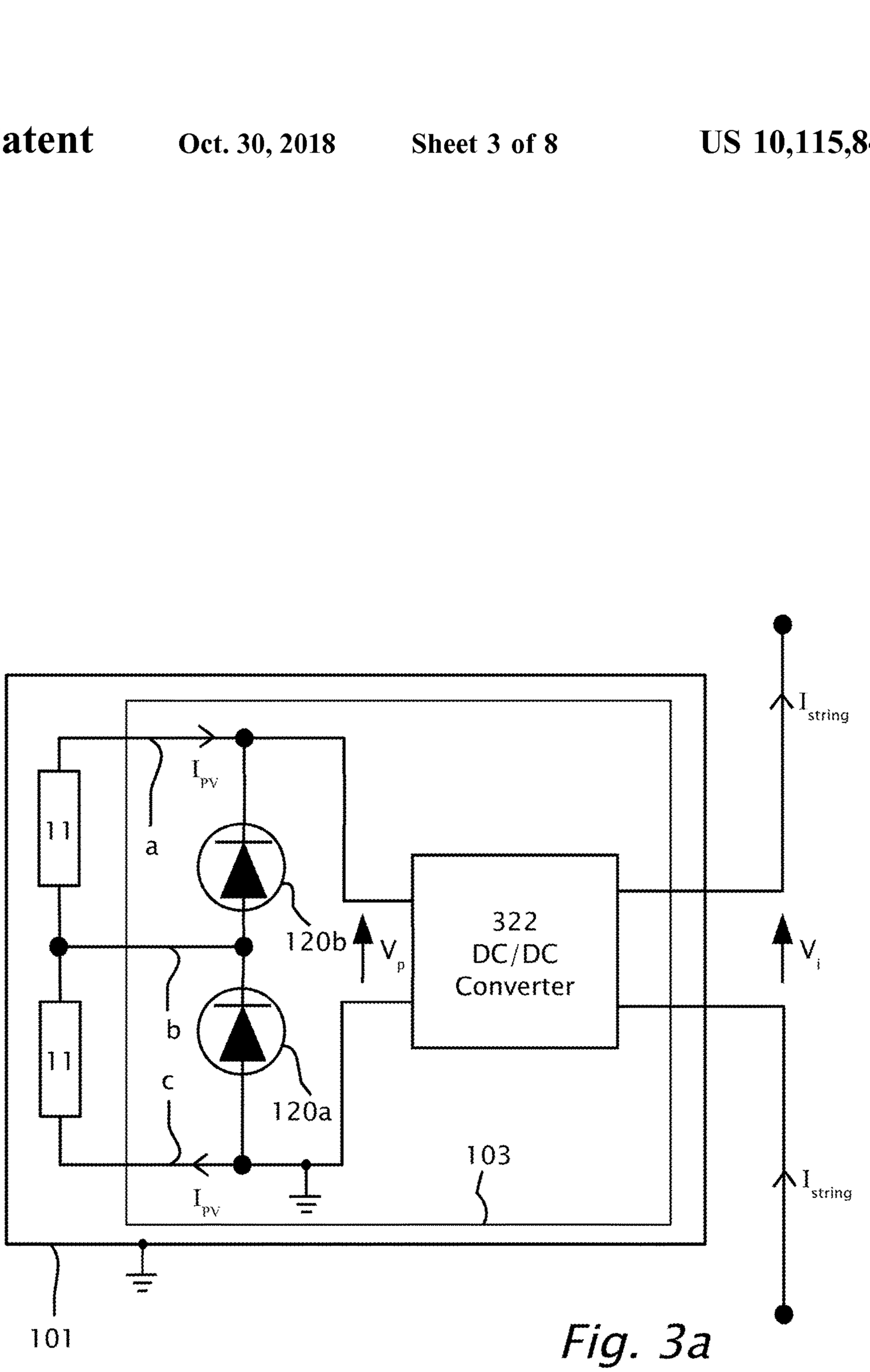

I_string
I_PV
11
a
120b
V_p
322
DC/DC
Converter
V_i
b
11
c
120a
103
I_PV
I_string
101

Fig. 3a

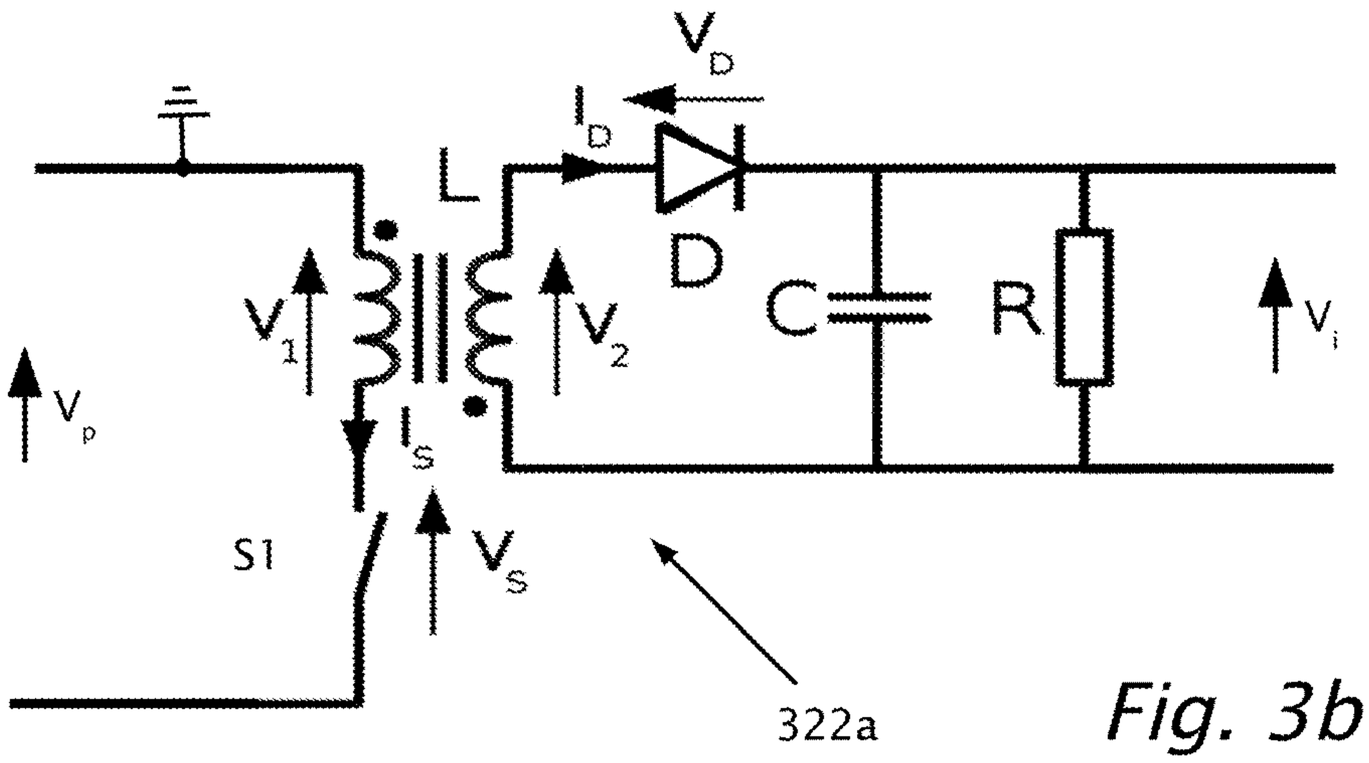


Fig. 3b

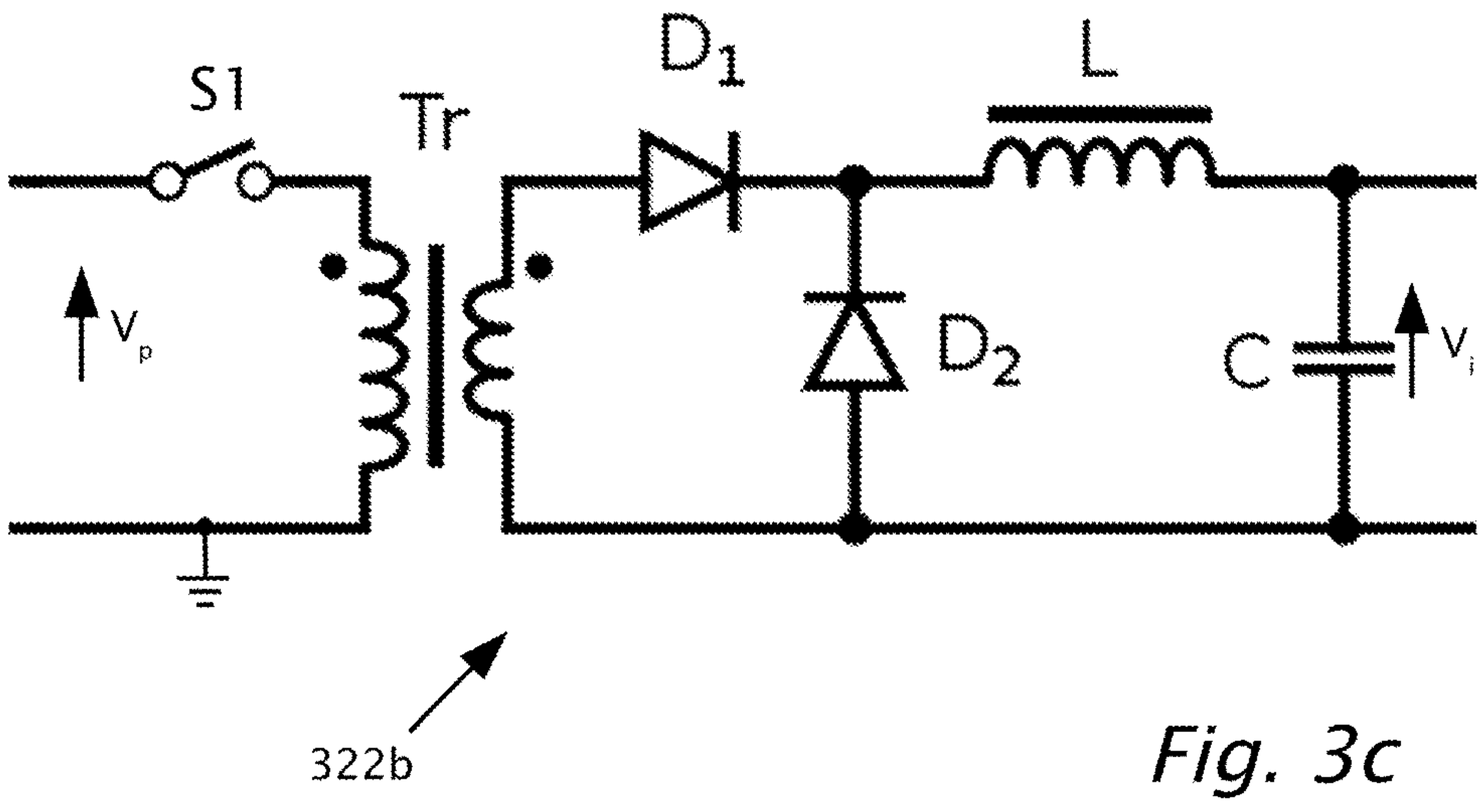


Fig. 3c

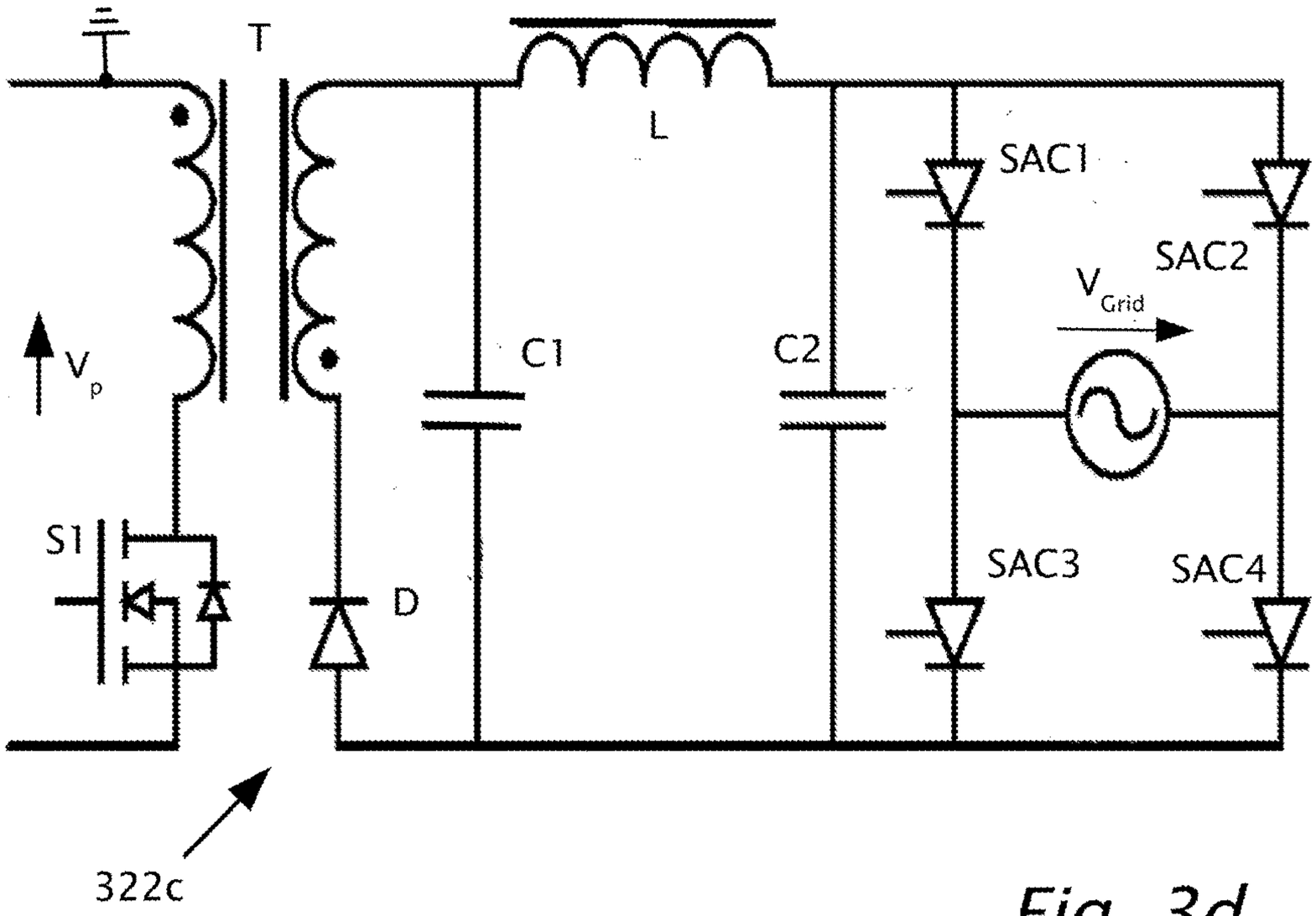

T
L
SAC1
SAC2
V_{Grid}
C1
C2
V_p
S1
D
SAC3
SAC4
322c

Fig. 3d

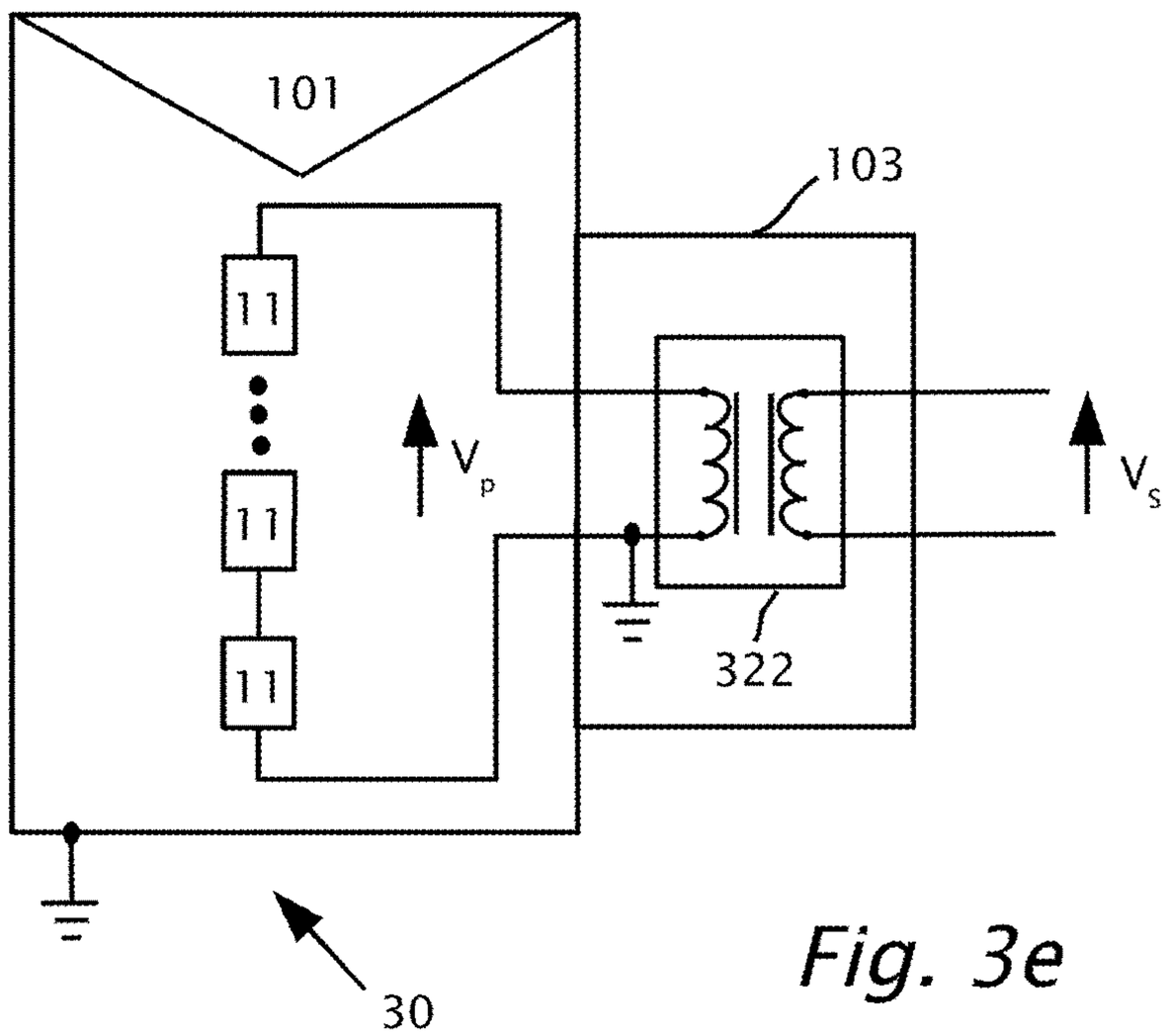

101
103
11
11
11
V_p
V_s
322
30

Fig. 3e

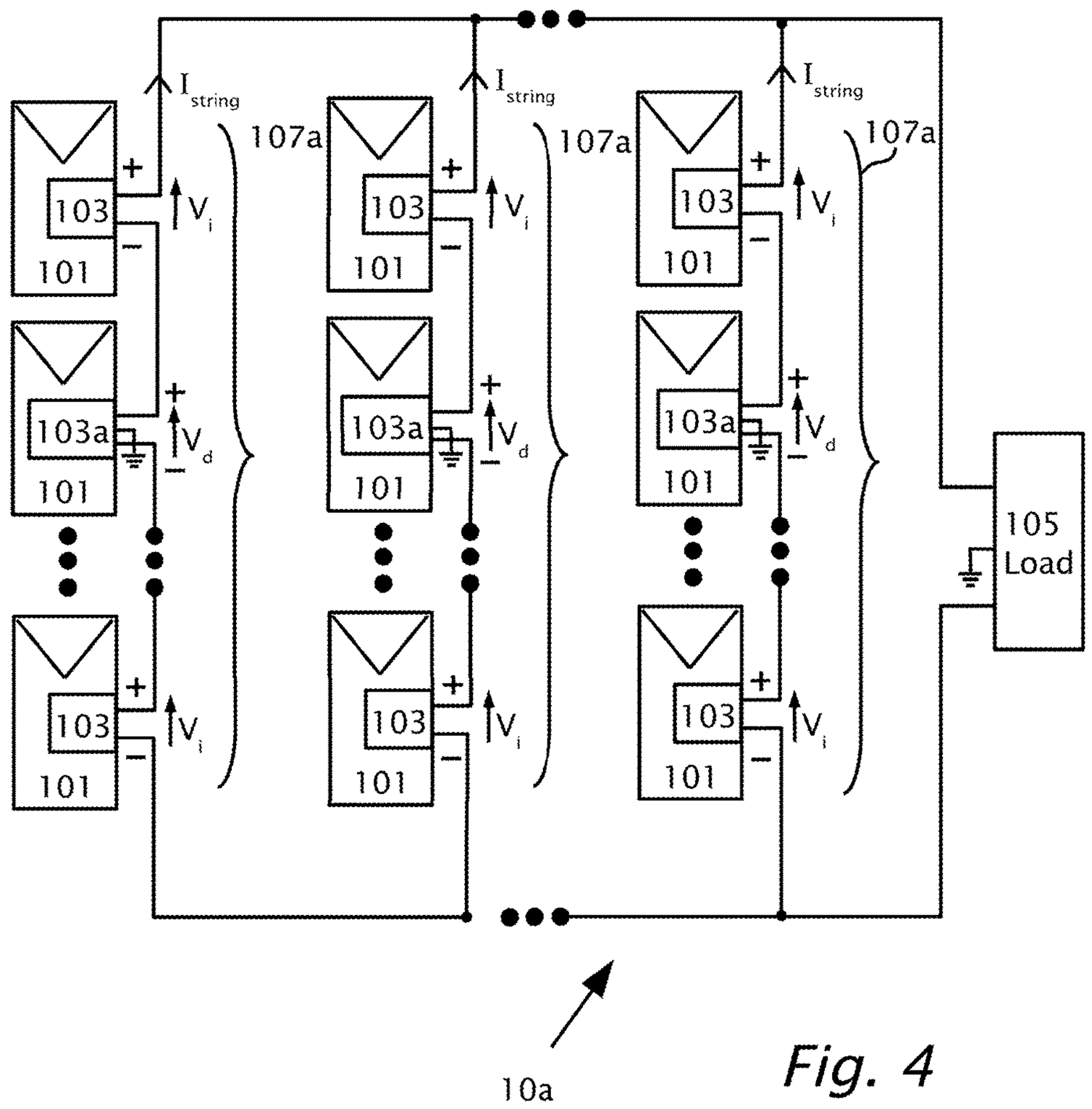


Fig. 4

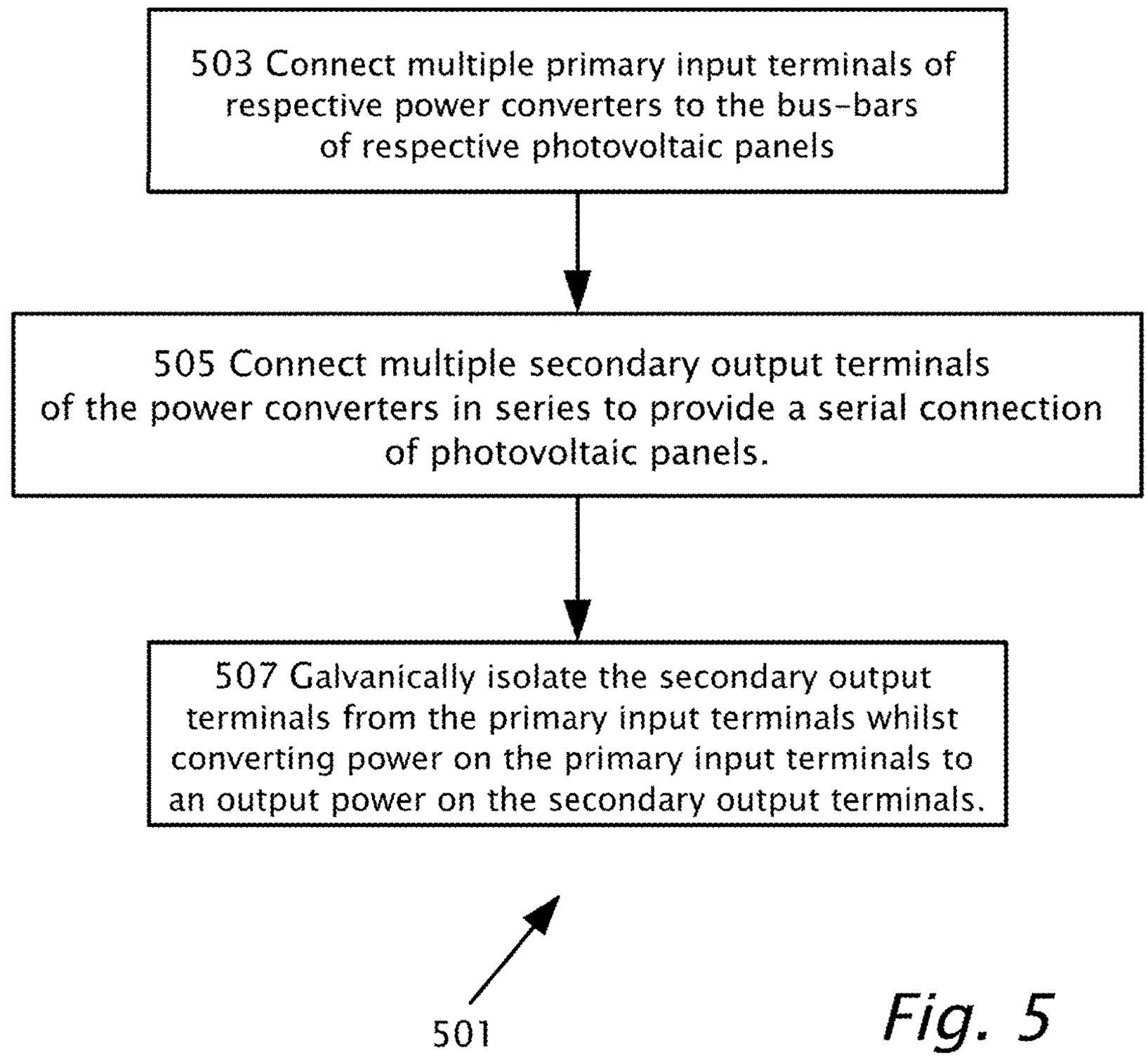

503 Connect multiple primary input terminals of respective power converters to the bus-bars of respective photovoltaic panels
505 Connect multiple secondary output terminals of the power converters in series to provide a serial connection of photovoltaic panels.
507 Galvanically isolate the secondary output terminals from the primary input terminals whilst converting power on the primary input terminals to an output power on the secondary output terminals.
501

Fig. 5

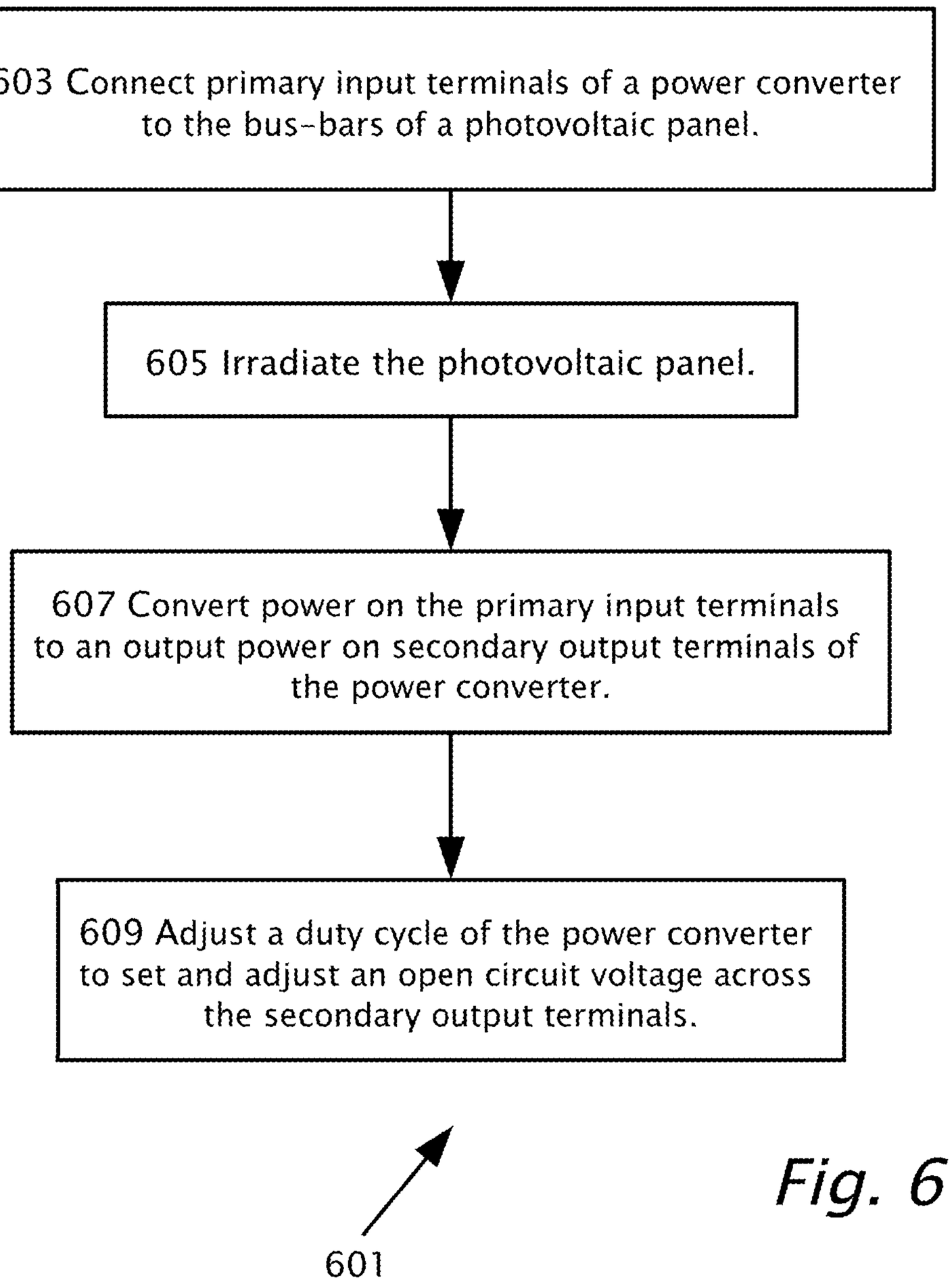

603 Connect primary input terminals of a power converter to the bus-bars of a photovoltaic panel.
605 Irradiate the photovoltaic panel.
607 Convert power on the primary input terminals to an output power on secondary output terminals of the power converter.
609 Adjust a duty cycle of the power converter to set and adjust an open circuit voltage across the secondary output terminals.
601

Fig. 6

INTEGRATED PHOTOVOLTAIC PANEL CIRCUITRY

BACKGROUND

A photovoltaic panel or a solar panel is an interconnected assembly of solar cells and is the basic component of a photovoltaic system.

Manufacturers of photovoltaic panels specify electrical characteristics which may include maximum rated power, open circuit voltage, short circuit current, maximum power voltage, maximum power current, temperature coefficients and insulation resistance.

Insulation resistance testing may be carried out by shorting a positive terminal and a negative terminal of a solar panel, and then by applying a predetermined voltage between the live electrical section and the outer housing, backside, the frame, and ground terminals. Wet insulation testing of photovoltaic panels may include performing resistance measurement on the insulation of a photovoltaic panel immersed in a liquid solution bath. The insulation resistance test and wet insulation test verifies that the solar panel or the solar cell array has insulation high enough to reduce the possibility of fire and electrocution hazards.

An increase in maximum system voltage may place an extra burden on photovoltaic manufacturers with regard to insulation resistance. Further, photovoltaic modules can exhibit performance degradation in the field when subjected to high voltages at elevated temperatures in a humid climate. Given that increased system voltage may place an extra burden on panel manufacturers to provide better insulation, and given that increased maximum system voltage may be a cause of performance degradation of photovoltaic modules, there is a need for and it would be advantageous to have circuitry integrated with a photovoltaic panel which provides features to allow more photovoltaic panels to be wired serially in a string without needing higher insulation resistance of the photovoltaic panel and lower operating voltage operation of photovoltaic panels so as to increase long term lifetime of a photovoltaic system.

SUMMARY

Various circuits are disclosed which are integrated or integrable with a photovoltaic panel to provide built-in functionality to the photovoltaic panel.

According to various aspects disclosed herein, there is provided a photovoltaic module which may include a photovoltaic panel and an isolated converter circuit with a primary input connected to the photovoltaic panel and a secondary output galvanically isolated from the primary input. The primary input may be connectible to multiple input terminals within a junction box and at least one of the input terminals may be electrically connected to a ground.

The photovoltaic module may include multiple interconnected photovoltaic cells connected electrically to multiple connectors (for example bus-bars). The photovoltaic module may include input terminals operable for connecting to the connectors and an isolated converter circuit. The isolated converter circuit may include a primary input connected to the input terminals and a secondary output galvanically isolated from the primary input. The isolated converter circuit may convert DC power on the primary input to a DC power on the secondary output. A duty cycle of the isolated converter circuit may be adjustable to give a nominal voltage on the secondary output. The duty cycle of the isolated converter circuit may be adjustable to give an adjustable open circuit voltage across the secondary output. The isolated converter circuit may be a Cuk circuit, a buck circuit, a buck-boost circuit, a buck and boost circuit, a boost circuit, a full-bridge circuit, a half-bridge circuit, a push-pull circuit, a resonant forward circuit, a forward circuit, a half-forward circuit, a ringing choke converter or a flyback circuit.

The photovoltaic module may be galvanically isolated from the primary input. The secondary output may be a dual direct-current (DC) output or a single direct-current (DC) output. The primary input may be a dual direct-current (DC) input from the connectors (for example bus-bars) or a single direct-current (DC) input from the connectors. Both the primary input and the secondary output may be dual direct-current (DC) input and output respectively or may be a single direct-current (DC) input and output respectively. The primary input and the secondary output may be a single direct-current (DC) input and a dual direct-current (DC) output respectively or may be a dual direct-current (DC) input and a single direct-current (DC) output respectively.

According to various aspects, there is provided a power harvesting system which includes multiple photovoltaic cells, and/or panels. Multiple isolated converter circuit modules with respective primary inputs, which may be integrable with and electrically connectable to respective photovoltaic panels. The power harvesting system may further include multiple interconnected photovoltaic strings. Each photovoltaic string may be a series connection of secondary outputs of the isolated converter circuit modules and the secondary outputs may be galvanically isolated from the primary inputs. A duty cycle of the isolated converter circuit modules may be adjustable to give an adjustable nominal voltage across the interconnected photovoltaic strings. A load may also be connected across the photovoltaic strings. The load may be a DC to alternating current (AC) inverter, a three-level DC to AC inverter, a grid tied DC to AC inverter, a DC battery, a DC motor or a DC to DC converter input.

According to various aspects, there is provided a method to reduce the voltage rating of a serial connection of photovoltaic panels in a solar power harvesting system. The method connects multiple primary input terminals of respective power converters to the connectors (for example bus-bars) of respective photovoltaic panels. Multiple secondary output terminals of the power converters are connected together to provide the serial connection. The secondary output terminals are galvanically isolated from the primary input terminals.

According to various aspects, there is provided a method for providing an adjustable open circuit voltage at the output terminals of a photovoltaic module. The method connects primary input terminals of a power converter to the connectors (for example bus-bars) of the photovoltaic panel. Power on the primary input terminals may be converted to an output power on secondary output terminals of the power converter. A duty cycle of the power converter may be adjusted to set and adjust an open circuit voltage across the secondary output terminals.

DESCRIPTION OF THE DRAWINGS

Various embodiments are herein described, by way of example only, with reference to the accompanying drawings, wherein:

FIG. **1** illustrates a photovoltaic solar power harvesting system, illustrating features of various embodiments.

FIG. **2***a* shows a cross section of a photovoltaic panel.

FIG. **2***b* which shows a plan view the photovoltaic panel shown in FIG. **2***a*.

FIG. **3***a* shows details of a circuit and a photovoltaic panel shown in FIG. **1**, according to an illustrative embodiment.

FIGS. **3***b* and **3***c* show two illustrative circuits for a DC/DC converter shown in FIG. **3***a* which are operable by a controller.

FIG. **3***d* shows an isolating DC to alternating current (AC) inverter, according to an illustrative embodiment.

FIG. **3***e* which shows a photovoltaic module, according to an illustrative embodiment.

FIG. **4** shows an alternative photovoltaic solar power harvesting system, according to various aspects.

FIG. **5** which shows a method which may be applied to the system and junction boxes shown in FIG. **1**, according to an illustrative feature.

FIG. **6** shows a method according to various embodiments.

DETAILED DESCRIPTION

Reference will now be made in detail to features of various embodiments, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to the like elements throughout. The features are described below to explain various embodiments by referring to the figures.

Before explaining various aspects in detail, it is to be understood that embodiments are not limited in their application to the details of design and the arrangement of the components set forth in the following description or illustrated in the drawings. Embodiments are capable of other features or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

It should be noted, that although the discussion herein relates primarily to photovoltaic systems, various embodiments may, by non-limiting example, alternatively be configured using other distributed power systems including (but not limited to) wind turbines, hydro turbines, fuel cells, storage systems such as battery, super-conducting flywheel, and capacitors, and mechanical devices including conventional and variable speed diesel engines, Stirling engines, gas turbines, and micro-turbines.

By way of introduction, various aspects are directed to circuitry integrated or integrable with a photovoltaic panel to form a photovoltaic module. The circuitry allows for galvanic isolation between the photovoltaic panel and the output of the circuitry.

According to an illustrative feature of various embodiments, the circuit is connected or connectible at the input terminals to a photovoltaic panel. The output terminals may be connected to form a string of photovoltaic modules. Multiple photovoltaic modules may be parallel connected to form the photovoltaic solar power harvesting system

The term "switch" as used herein may refer in various embodiments to an active semiconductor switch, e.g. a field effect transistor (FET), in which a controllable and/or variable voltage or current is applied to a control terminal, e.g. gate, of the switch which determines the amount current flowing between the poles of the switch, e.g. source and drain of the FET.

The term "activate" a switch as used herein may refer to opening, closing and/or toggling i.e. alternatively opening and closing the switch.

The term "galvanic isolation" as used herein is a way of isolating functional sections of electrical circuits and/or systems from the movement of charge-carrying particles from one section of an electrical circuit and/or a system to another. That is, there is no direct current between the functional sections of electrical circuits and/or systems. Energy or information, however, can still be exchanged between the sections of electrical circuits and/or systems by other means, e.g. capacitance, mutual inductance or electromagnetic waves, or by optical, acoustic or mechanical means.

The term "dual DC" input or output may refer in various embodiments to positive and negative terminals referenced to each other and referenced to a third terminal, such as ground potential, electrical ground or a neutral of an alternating current (AC) supply which may be connected to electrical ground at some point.

The term "single DC" input or output refers to positive and negative terminals referenced to each other, but not referenced or connected to a ground potential, electrical ground or a neutral of an alternating current (AC) supply, unless one of the terminals is coupled to a reference.

The term "two-level inverter" as used herein, refers to and inverter having an AC phase output having two voltage levels with respect to a negative terminal. The negative terminal is common to the AC phase output and the direct current (DC) input of the two-level inverter. The alternating current (AC) phase output of the two-level inverter may be a single phase output a two phase output or a three phase output. Therefore, the single phase output has two voltage levels with respect to the negative terminal. The two phase output has two voltage levels with respect to the negative terminal for each of two phases. The three phase output has two voltage levels with respect to the negative terminal for each of three phases.

Similarly, the term "three-level inverter" as used herein refers to and inverter having an alternating current (AC) phase output having three voltage levels. The AC phase output has three voltage levels with respect to a negative terminal. The negative terminal may be common to the AC phase output and the direct current (DC) input of the three-level inverter. The alternating current (AC) phase output of the three-level inverter may be a single phase output, a two phase output, or a three phase output. Therefore, the single phase output has three voltage levels with respect to the negative terminal. The two phase output has three voltage levels with respect to the negative terminal for each of the two phases. The three phase output has three voltage levels with respect to the negative terminal for each of the three phases.

The three-level inverter compared with the two-level inverter may have a cleaner AC output waveform, may use smaller size magnetic components and may have lower losses in power switches, since more efficient lower voltage devices may be used. Three-level inverter circuits may have dual (positive and negative) direct current (DC) inputs.

Reference is now made to FIG. **1** of a photovoltaic solar power harvesting system **10**, illustrating various aspects. Power harvesting system **10** includes multiple photovoltaic panels **101** connected respectively to multiple junction boxes **103** to form multiple photovoltaic modules. Junction box **103** may provide electrical input terminals and mechanical support for bus-bars a, b and c (not shown), which may be used as an input to junction box **103** from panel **101**. Junction box **103** may be attachable and/or re-attachable to panel **101** or may be permanently attachable to panel **101** using for example a thermoset adhesive, e.g. an epoxy

adhesive, screws, or other mechanical attachment. The electrical voltage outputs (V_i) at output terminals of junction boxes **103** may be connected in series to form a series photovoltaic serial string **107** through which a string current (I_{string}) may flow. Multiple strings **107** may be connected in parallel and across an input of a load **105**. V_i and I_{string} may be different for every photovoltaic module and string **107**, respectively. Load **105** may be a direct current (DC) load such as a DC motor, a battery, an input to a DC to DC converter, or a DC input to a DC to AC inverter.

Reference is now made to FIG. **2***b*, which shows a plan view photovoltaic panel **101**. The plan view shows casing **220** and photovoltaic cells **252** with tracks **250** showing through transparent glass **228** and sheet **224***b*.

Reference is now made to FIG. **2***a* which shows a partial cross section **290** of section YY shown in FIG. **2***b* for a photovoltaic panel **101**. The partial cross section is located near a side **220***a* of casing **220**. Side **220***a* is located at the perimeter of casing **220** as illustrated in FIG. **2***b*. Casing **220** includes a back **220***b* and four sides **220***a*. Casing **220** may be fabricated using a metal alloy, aluminum, stainless steel, plastic or other material having sufficient strength to house the panel components. Casing **220** may hold together a sandwich of various sheets. Nearest to back **220***b* is an insulating sheet **222**. Next to insulating sheet **222** is a reactive encapsulant sheet **224***a*. Encapsulant sheet **224***a* may be made from a polymer, e.g., ethylene vinyl acetate (EVA) polymer, polyvinyl-butyral (PVB), etc. Next to reactive encapsulant sheet **224***a* is a photovoltaic substrate **226** followed by another reactive encapsulant sheet **224***b*, that may be transparent. Encapsulant sheet **224***b* may be made out of the same or similar material as **224***a*. Finally after reactive encapsulant sheet **224***b* is a sheet of low iron flat glass **228**. The side (i.e., surface) of photovoltaic substrate **226** adjacent to reactive encapsulant sheet **224***b* is where the metal tracks **250** (not shown) may be located. Metal tracks **250** connect electrically the photovoltaic cells **252** (not shown) of photovoltaic substrate **226**. Junction box **103** may be mounted on back **220***b* and bus-bars a, b and c (not shown) may terminate inside junction box **103** and connect to tracks **250**. In other embodiments, junction box **103** is mounted separate from panel **101**.

Reference is now made to FIG. **3***a* which shows more details of junction box **103** and photovoltaic panel **101** shown in FIG. **1**, according to an illustrative feature. According to the example, photovoltaic panel **101** includes two sub-strings **11** of serially connected photovoltaic cells which output to bus-bars a, b and c which are the input terminals to junction box **103**. Sub-strings **11** may include one or more cells. The input of junction box **103** may include two bypass diodes **120***a* and **120***b* with anodes connected respectively to bus-bars c and b and cathodes connected respectively to bus-bars a and b. Connected across bus-bars a and c is the input to a direct current (DC) to DC converter **322**. When sub-strings **11** are illuminated, the current into converter **322** is substantially that of current I_{PV} flowing from strings **11** and the voltage V_P input to converter **322** is the voltage across bus-bars a and c. The output of converter **322** is V_i and the output of a converter **322** may be placed in series with other panels **101** and/or junction boxes **103** to form a string **107** as shown in FIG. **1**.

Reference is now made to FIGS. **3***b* and **3***c* which show implementations of converter **322** shown in FIG. **3***a*, according to various embodiments. Both FIGS. **3***b* and **3***c* are isolating DC to DC converters shown by converter circuits **322***a* and **322***b* respectively. Converters **322***a* and **322***b* have primary inputs (V_P) which may be connected across a panel **101** as shown in FIG. **3***a* and secondary outputs (V_i) which may be connected in series to form a serial string **107** as shown in FIG. **1**.

Converter **322***a* has a single switch **S1** wired in series with a primary side of a mutual inductor L. The secondary side of inductor L is wired in series with a diode D. The anode of diode D may be connected to one end of inductor L and the cathode of diode D may be connected to the positive voltage terminal of secondary output Vi. The other end of inductor L not connected to diode D may be connected to the negative terminal of secondary output Vi. A resistor R and capacitor C may be wired in parallel across the secondary output V_i. In an alternate version, the cathode of diode D may be connected to one end of inductor L, the anode of diode D may be connected to the negative terminal of secondary output Vi, and the other end of inductor L not connected to diode D may be connected the positive terminal of secondary output Vi. A resistor R and capacitor C may be wired in parallel across secondary output V_i in the alternate version.

Converter **322***a* may be an isolating buck-boost converter with the inductor (L) split to form a transformer, so that voltage ratios of V_1 and V_2 are multiplied as well as having galvanic isolation between primary input V_P and secondary output V_i.

Converter **322***b* may have a single switch **S1** wired in series with a primary side of a transformer Tr. Again transformer Tr provides galvanic isolation between primary input V_P and secondary output V_i. One end of the secondary winding of transformer Tr may connect to the anode of a diode **D1** and the cathode of **D1** may connect to one end of an inductor L. The other end of inductor L may be connected to the positive voltage terminal of secondary output V_i. The other end of the secondary winding may be connected to the negative voltage terminal of secondary output V_i. The other end of the secondary winding may connect to the anode of diode **D2** and the cathode of **D2** may connect to the cathode of diode **D1**. A capacitor C may be connected across secondary output V_i. Other variation of converter **322***b* may be used with **D1**, **D2**, L and C used in various other arrangements to provide the same output Vi Converter **322***b* may be a forward converter and performs the same function of converter **322***a* and may be more energy efficient than converter **322***a*. Numerous other isolated DC to DC converter topologies may be used with respect to converter **322**, for example, ringing choke converter, resonant forward, half-bridge and full-bridge converters. A feature of DC to DC converters may be an adjustable duty cycle for conversion of DC power. Converters **322***a* and **322***b*, therefore, may be adjusted to give an adjustable desired open circuit voltage across secondary output V_i prior to connection in a string **107**.

Reference is now made to FIG. **3***d* which shows an isolating DC to alternating current (AC) isolating inverter **322***c*, according to an illustrative feature. A switch **S1** may be wired in series with the primary side of a transformer T. In some variations, switch **S1** may be a metal oxide semiconductor field effect transistor (MOSFET). A DC voltage (V_P) may be applied across the source of switch **S1** and one side of primary coil T. The other side of primary coil T may be connected to the drain of switch **S1**. In some variations the source and drain of **S1** may reversed. A diode D may be connected in series with the secondary coil with of transformer T with the cathode of D connected to one end of the coil. Connected across the series connection of the secondary coil of transformer T and diode D may be capacitor **C1**. One end of capacitor **C1** may be connected to the anode of diode D and the other end of capacitor **C1** may be connected

to the end of the secondary coil not connected to the diode D. The end of the secondary coil not connected to diode D may also be connected to one end of an inductor L and the other end of inductor L connected to anodes of switch control rectifiers SAC**1**, SAC**2** and one end of capacitor C**2**. The other end of capacitor C**2** may connect to the anode of diode D and the cathodes of switch control rectifiers SAC**3** and SAC**4**. The cathode of switch control rectifier SAC**1** may connect to the anode of switch control rectifier SAC**3** to form a first terminal of secondary AC output V_{Grid}. The cathode of switch control rectifier SAC**2** may connect to the anode of switch control rectifier SAC**4** to form a second terminal of secondary AC output V_{Grid}. Multiple secondary AC outputs (V_{Grid}) from multiple inverters **322***c* may be connected in either series to give a series AC string or in parallel to give a parallel AC string.

Converter circuits **322***a*, **322***b* and **322***c* may having one terminal of respective primary sides (V_P) connected to a ground and/or casings **220** of panels **101** which may also be connected to the ground. The ground may be electrical earth and/or a local earth provided in the immediate vicinity of panels **101**. Further connections to electrical earth may be made by bonding to casings **220** of panels **101** and framework used to mount panels **101**.

Reference is now made to FIG. **3***e* which shows a photovoltaic module **30**, according to an illustrative feature. Photovoltaic module **30** includes one or more panels **101** series connected with sub-strings **11** which are in series and connected across the primary input (V_P) of an isolating converter **322**. Converter **322** provides a secondary output (V_S) which may be galvanically isolated from the primary input (V_P). The secondary output (V_S) may be DC and/or AC. Circuitry of converter **322** may be integrated or integrable with a photovoltaic panel **101** and/or housed in a junction box **103**.

Reference is now made to FIG. **5** which shows a method **501** which may be applied to system **10**/**10***a* and junction boxes **103**, according to an illustrative feature as shown in FIGS. **1** and **4**. With reference to FIG. **3***a*, in step **503**, a single primary DC input (V_P) of converter **322** is connected to bus-bars a and c via terminations, which may be located in in junction box **103**. Where converter **103** has a dual DC input, connection may be made to bus bar b. In the case of dual DC input into converter **322** bus bar b may be additionally connected to a local ground or electrical earth. Similar connections may be made in multiple converters **322** (which may be in respective multiple junction boxes **103**) integrated with panels **101**. In step **505**, the outputs (V_i) of converters **322** may be wired in series to form a string **107** illustrated in FIG. **4**. During the irradiation of strings **107** if an isolating converter **322** is used, in step **507**, DC power on the primary input (V_P) may be converted with galvanic isolation to the secondary output (V_i). The galvanic isolation between primary input (V_P) and secondary output (V_i), may additionally allow for different ground potentials on either side of the primary input (V_P) and the secondary output (V_i). The galvanic isolation of different ground potentials, on either side of **322**, may allow for use of various configurations of single or dual DC input and/or outputs on the primary inputs (V_P) and the secondary outputs (V_i) within string **107**, since each V_P may be isolated from every other V_P.

By way of numerical example, a comparison may be made between ten panels **101** having converters **322** in a string **107** and ten panels without converters **322** connected in a serial string. In the serial string the first panel **101** has the negative terminal connected to a ground and the chassis of the first panel **101** connected to the ground as well. The remaining nine panels **101** only have their respective chassis connected to the ground. If the output of each panel is 40 Volts, then the top tenth panel **101** has a voltage of 10 times 40V=400 Volts at its positive output terminal and the ninth panel has voltage of 9 times 40=360 Volts at its positive output terminal. By comparison in a string **107** using isolating converters, the primary side of the respective converters **322** have a ground connection as shown in FIG. **3***e* as well as the chassis of each respective panel **101** being connected to the ground as well. In such a string **107** with isolating converters **322**, the primary side and hence the output of each panel **101** is at 40 Volts by virtue of the galvanic isolation between the primary side and the secondary side of each respective converter **322**. The secondary sides of converters **322** in series string **107** still give 10 times 40V=400 Volts but each panel **101** in string **107** only operates at 40 Volts with respect to the ground. Therefore, the voltage rating of each panel **101** in a string **107** is only 40 Volts compared to the panels **101** in the serial string of panels **101**. Panels **101** in the serial string may have to have a voltage rating of at least 400 Volts if the first panel **101** has the negative terminals connected to the ground and possibly a much greater rating of 400 Volts if the first panel **101** has the negative terminal not connected to the ground. The negative terminal not connected to the ground may allow the voltage of the serial string to float, so that the tenth panel **101** in the serial string may have a voltage greater than 400 Volts.

Further, as shown in FIG. **4**, the series string of secondary outputs of converters **322** may be referenced to ground at various points to provide a reduced maximum voltage with respect to the ground reference of the primary side. For example, a secondary output of an intermediate converter in each string may be grounded, such that converters connected in the string on one side (e.g., the positive side) of the ground point may have a positive voltage with respect to ground, and converters connected in the string on the other side (e.g., the negative side) of the ground point have a negative voltage. In the example above, the 400V across the secondary output string can be referenced to a range of −200V to +200V with respect to the ground reference. Thus, the maximum primary to secondary side voltage difference can be reduced from 400V to 200V. Reference is now made to FIG. **6** which shows a method **601** which may be applied to system **10**/**10***a* and a junction box **103**, according to an illustrative feature. Method **601** may be applied to junction box and/or panel **101**, prior to making a series connection of the outputs (V_i) of converters **322** to form a string **107**. In step **603**, a single primary DC input (V_P) of converter **322** is connected to bus-bars a and c via terminations, which may be located in junction box **103**. Where converter **103** has a dual DC input, connection may be made to bus bar b. In step **605** a panel **101** may be then irradiated to provide a voltage on the primary input (V_P) of converter **322**. Alternatively, another DC voltage source may be connected to the primary input (V_P) of converter **322**. With a panel **101** connected (step **603**) to the primary input (V_P) and the panel **101** irradiated (step **605**) or DC voltage applied to the primary input (V_P), DC power on the primary input (V_P) may be converted with galvanic isolation to the secondary output (V_i). During the conversion of power by converter **322**, the duty cycle of converter **322** may be adjusted to vary and set the open circuit voltage on the secondary output (V_i) of converter **322** (step **609**). Alternatively, the duty cycle of converter may be adjusted to vary and set the operating

voltage on the secondary output (V_i) of converter **322** when the secondary output (V_i) is connected to a load and/or within a string **107**.

The indefinite articles "a", "an" is used herein, such as "a photovoltaic panel", "a junction box" have the meaning of "one or more" that is "one or more photovoltaic panels" or "one or more junction boxes".

Aspects of the disclosure have been described in terms of illustrative embodiments thereof. While illustrative systems and methods as described herein embodying various aspects of the present disclosure are shown, it will be understood by those skilled in the art, that the disclosure is not limited to these embodiments. Modifications may be made by those skilled in the art, particularly in light of the foregoing teachings. For example, each of the features of the aforementioned illustrative examples may be utilized alone or in combination or sub combination with elements of the other examples. For example, any of the above described systems and methods or parts thereof may be combined with the other methods and systems or parts thereof described above. For example, one of ordinary skill in the art will appreciate that the steps illustrated in the illustrative figures may be performed in other than the recited order, and that one or more steps illustrated may be optional in accordance with aspects of the disclosure. It will also be appreciated and understood that modifications may be made without departing from the true spirit and scope of the present disclosure. The description is thus to be regarded as illustrative instead of restrictive on the present disclosure.

The invention claimed is:

1. An apparatus comprising:

a photovoltaic panel comprising a plurality of photovoltaic cells;

a casing that holds the photovoltaic cells; and

a converter circuit comprising first and second input terminals, the first input terminal directly connected to the casing by the first input terminal being bonded to the casing, and the second input terminal directly connected to the photovoltaic panel, and the converter circuit comprising first and second output terminals galvanically isolated from the first and second input terminals and electrically disconnected from the first and second input terminals, wherein the converter circuit converts first direct current (DC) power on the second input terminal to second DC power on the first output terminal, wherein the first output terminal of the converter circuit outputs power received by the converter circuit,

wherein the first and second input terminals of the converter circuit are integrated with the casing and the photovoltaic panel, respectively.

2. The apparatus of claim **1**, further comprising:

a junction box comprising a plurality of terminals, wherein the first and second input terminals of the converter circuit are connected to the plurality of terminals of the junction box, wherein the converter circuit is housed within the junction box, and wherein the junction box is directly attached to the photovoltaic panel.

3. The apparatus of claim **1**, wherein the casing is a metal component, and wherein the casing and the first input terminal of the converter circuit are connected to ground.

4. The apparatus of claim **1**, wherein the first input terminal of the converter circuit is further connected to the photovoltaic panel.

5. The apparatus of claim **1**, wherein the casing comprises:

a back; and

four sides,

wherein an upper surface the photovoltaic cells are directly exposed to a region outside the casing when held by the casing.

6. The apparatus of claim **1**, further comprising:

an insulating sheet in direct contact with the photovoltaic panel,

wherein the insulating sheet is disposed between the casing and the photovoltaic panel, and

wherein the insulating sheet provides an insulation resistance for the photovoltaic panel such that the photovoltaic panel is insulated to an insulation level that provides protection to withstand a voltage corresponding to a maximum voltage capable of being output by the photovoltaic panel.

7. The apparatus of claim **6**, wherein the converter circuit is connected to at least one other converter circuit disposed upstream with respect to the converter circuit in a series string of N converter circuits, N being a positive integer greater than one, the at least one other converter circuit having an input terminal directly connected to an output terminal of a second photovoltaic panel that is connected serially with the photovoltaic panel, the input terminal of the at least one other converter circuit being galvanically isolated from an output terminal of the at least one other converter circuit.

8. The apparatus of claim **7**, wherein the maximum voltage capable of being output by the photovoltaic panel is a voltage capable of being output by the photovoltaic panel, between first and second output terminals of the photovoltaic panel, when the photovoltaic panel is a most upstream photovoltaic panel in a series string of N photovoltaic panels respectively connected on a one-to-one basis to a series string of N converter circuits.

9. The apparatus of claim **8**, further comprising:

a transformer that galvanically isolates the first and second output terminals from the first and second input terminals of the converter circuit, the transformer including a primary side and a secondary side, the primary side including a first end and a second end,

wherein a switch is connected in series to the first end of the primary side of the transformer or the second end of the primary side of the transformer, and

wherein no other switches are connected to the primary side of the transformer.

10. An apparatus comprising:

a photovoltaic panel configured to generate a first voltage at output terminals, the photovoltaic panel comprising a plurality of photovoltaic cells;

a casing that holds the photovoltaic cells; and

a converter circuit comprising a first input terminal directly connected to the casing by the first input terminal being bonded to the casing, and a second input terminal directly connected to the photovoltaic panel and configured to receive the first voltage, the converter circuit including first and second output terminals galvanically isolated from the first and second input terminals and electrically disconnected from the first and second input terminals, wherein the casing is connected to ground,

wherein the first and second input terminals of the converter circuit are integrated with the casing and the photovoltaic panel, respectively.

11. The apparatus of claim **10**, further comprising:

a transformer that galvanically isolates the first and second output terminals from the first and second input

terminals of the converter circuit, the transformer including a primary side and a secondary side, the primary side including a first end and a second end; and

a switch,

wherein the switch is connected in series to the first end of the primary side of the transformer or the second end of the primary side of the transformer, and

wherein no other switches are connected to the primary side of the transformer.

12. The apparatus of claim **10**, wherein the first input terminal of the converter circuit is further connected to the photovoltaic panel.

13. The apparatus of claim **10**, further comprising:

a junction box comprising a plurality of input terminals, wherein the first and second input terminals of the converter circuit are connected to the plurality of input terminals of the junction box, wherein at least one of the plurality of input terminals of the junction box is electrically connected to a ground, wherein the converter circuit is housed within the junction box, and wherein the junction box is directly attached to a surface of the photovoltaic panel.

14. The apparatus of claim **10**, wherein the converter circuit includes a switch having a first terminal directly connected to either the first input terminal or the second input terminal of the converter circuit, and the switch having a second terminal directly connected to circuitry configured to galvanically isolate the first and second output terminals from the first and second input terminals of the converter circuit, and wherein a duty cycle of the switch of the converter circuit is adjustable to give an adjustable open circuit voltage across the first and second output terminals of the converter circuit by opening and closing the switch in accordance with the duty cycle of the switch.

15. The apparatus of claim **10**, wherein the casing comprises:

a back; and

four sides,

wherein an upper surface the photovoltaic cells are directly exposed to a region outside the casing when held by the casing.

16. The apparatus of claim **10**, further comprising:

an insulating sheet in direct contact with the photovoltaic panel,

wherein the insulating sheet is disposed between the casing and the photovoltaic panel, and

wherein the insulating sheet provides an insulation resistance for the photovoltaic panel such that the photovoltaic panel is insulated to an insulation level that provides protection to withstand a voltage corresponding to a maximum voltage capable of being output by the photovoltaic panel.

17. The apparatus of claim **16**, wherein the converter circuit is connected to at least one other converter circuit disposed upstream with respect to the converter circuit in a series string of N converter circuits, N being a positive integer greater than one, the at least one other converter circuit having an input terminal directly connected to an output terminal of a second photovoltaic panel that is connected serially with the photovoltaic panel, the input terminal of the at least one other converter circuit being galvanically isolated from an output terminal of the at least one other converter circuit.

18. The apparatus of claim **17**, wherein the maximum voltage capable of being output by the photovoltaic panel is a voltage capable of being output by the photovoltaic panel, between first and second output terminals of the photovoltaic panel, when the photovoltaic panel is a most upstream photovoltaic panel in a series string of N photovoltaic panels respectively connected on a one-to-one basis to a series string of N converter circuits.

19. A method comprising:

attaching a photovoltaic panel comprising a plurality of photovoltaic cells to a casing, to thereby hold the photovoltaic panel by way of the casing;

housing a DC/DC converter circuit within a junction box, wherein the DC/DC converter circuit includes first and second input terminals, first and second output terminals, and a transformer that galvanically isolates the first and second input terminals from the first and second output terminals, wherein the first and second input terminals are electrically disconnected from the first and second output terminals;

directly connecting the first input terminal of the DC/DC converter circuit to the casing by bonding the first input terminal of the DC/DC converter circuit to the casing, and directly connecting the second input terminal of the DC/DC converter circuit to the photovoltaic panel; and

integrating the DC/DC converter circuit with the photovoltaic panel by directly attaching the junction box to an outer surface of the photovoltaic panel.

20. The method of claim **19**, further comprising:

placing an insulating sheet between the casing and photovoltaic panel in which the insulating sheet is in direct contact with the photovoltaic panel,

wherein the insulating sheet provides an insulation resistance for the photovoltaic panel such that the photovoltaic panel is insulated to an insulation level that provides protection to withstand a voltage corresponding to a maximum voltage capable of being output by the photovoltaic panel.

21. The method of claim **20**, wherein the maximum voltage capable of being output by the photovoltaic panel is a voltage capable of being output by the photovoltaic panel, between first and second output terminals of the photovoltaic panel, when the photovoltaic panel is a most upstream photovoltaic panel in a series string of N photovoltaic panels respectively connected on a one-to-one basis to a series string of N converter circuits.

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